Predicting Coke Stability from Petrographic Analysis of Illinois Coals

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ABSTRACT

Previously published curves based on coal petrography and coking data that have been used successfully in predicting the ASTM stability factor of coke were found to be not generally applicable to Illinois coals. Using Illinois coals or blends containing Illinois and other coals, petrographic analyses and coking data, derived from pilot coke oven tests, provided basic information for modifying these curves. The information is presented in this report. The application of petrographic data to the curves for predicting coke stability is demonstrated.

INTRODUCTION

Coal petrography, or the systematic and descriptive study of the physical components of coal, is a relatively new science that has developed rapidly since the early part of the 20th century. In the last 10 years, there has been increasing interest in the application of coal petrography for evaluating individual coals and blends of different coals used in the production of metallurgical coke. The increased interest has resulted largely from the development of procedures in which numerical values, determined from petrographic analyses of coals, permit prediction of the ASTM tumbler stability factor, which is the major basis of coke evaluation in the coking industry.

Systems of coal petrographic nomenclature, used by various laboratories, have not always been consistent. Some confusion has resulted from the inconsistent use of terms, both for the coal petrographer and the nonspecialist interested in the application of coal petrographic data. It is felt, however, that the importance of the varying nomenclature in coal petrography may have been exaggerated by some nonspecialists. Actually the similarities between the various systems far outweigh the differences between them.

Problems associated with improvements in petrographic nomenclature and methods of analysis are of importance to coal petrographers. However, efforts of coal petrographers to make these improvements should not be confused with the application of petrographic methods that have been developed. The most recent and

probably the best known development is the use of petrographic analysis of coal to provide data for predicting the stability factor of coke produced from that coal. National and international bodies of coal petrographers are currently considering problems of definitions, analytical methods, and classification systems. The results of these cooperative efforts undoubtedly will produce more uniformity in petrographic nomenclature and methods of analysis. It is emphasized, however, that the nomenclature of petrographic analysis should not adversely concern the coke technologists in the application of coal petrography because in the prediction of coke stability, the established terms of coke technology are used.

The primary objective of this report is to present petrographic data that was used to predict the stability factor of cokes which were derived from Illinois coals or blends containing Illinois and other coals. The secondary objective is to review in detail the method of evaluating the coke stability factor by the petrographic method.

Since 1935, the Illinois State Geological Survey has made extensive studies of the use of Illinois coals in blends for the production of metallurgical coke. The results of these studies have been reported in a number of publications (Thiessen, 1937; Reed and associates, 1947; Jackman and Helfinstine, 1961; and Risser, 1962). Although limited pilot coke oven results were related to petrographic investigations by Marshall and associates (1958), the present report presents for the first time, correlations of petrographic analyses of many Illinois coals and blends with the actual ASTM tumbler stabilities of cokes produced in the Survey's pilot coke oven.

Previous Investigations

Prior to 1913, many ideas were advanced to explain the nature and formation of coal, but in 1913 White and Thiessen published what is probably the first systematic study based on examination of the bright and dull bands of coal. They established a relation between these bands and the individual plant components from which the coal was derived, and they developed a systematic nomenclature to describe these materials.

Subsequently, a relatively small group of scientists in several coal producing countries of the world, has advanced the knowledge of coal by petrographic methods. These studies were, for the most part, independent and had markedly differing objectives, ranging from the most fundamental type of study to the most directly applied objective. The differing techniques of study and the varying objectives resulted in the use of different terms or different meanings for the same terms.

Most of the early studies of coal by microscope methods utilized thin sections of coal that were mounted on glass slides and ground to the thickness of approximately .0003 inch (about 8 microns). This rendered the principal constituents of bituminous coal translucent. This method of examination, used by Thiessen, permitted ready recognition of most of the plant constituents and resulted in a nomenclature and classification that considered coals as collections of recognizable plant materials. Thiessen's classification, which developed during his microscopic investigation of coals, was included in numerous papers but was never presented systematically. Parks and O'Donnell (1956) reviewed and summarized Thiessen's classification based upon his microscope criteria.

During the early 1920's, particularly in England and Germany, workers began petrographic examination of coal by reflected light from polished coal surfaces, measuring the amount of reflectance by means of the Berek photometer. These

methods are similar to those used in metallurgy. The physically differing coal materials, considered by this type of investigation, are called macerals (Stopes, 1935) and are analogous to mineral constituents of rocks.

Marshall (1955) presented a rather comprehensive review of work in the field of coal petrography up to the year 1950, listing over 300 references. The work of Stach and Hoffmann (1931), Hoffmann and Jenkner (1932), and Seyler (1943) particularly contributed to the evolution of methods used for the practical application of coal petrography, which is the subject of the present paper.

In 1958, Marshall et al., reported a comprehensive laboratory coking study that related petrographic composition to coking quality. Although this study gave insight into petrographic relations favorable to improved coking character of Illinois coals and evaluated many other factors that influence coking character, it did not set forth the foundation for predicting coke quality in terms of specific numerical values for coke stability or hardness.

In a 1957 report, Ammosov and associates presented, in broad outline, a method of using petrography to predict coke stability from coal and blends of coals. Schapiro and Gray (1960), following the basic methods of Ammosov, refined the procedure and developed basic data for many coals and related these data to standard methods of coke testing used in the United States.

Although the petrographic nomenclature employed differs from laboratory to laboratory in the United States, the basic method of predicting coke stability of coals is the one used at the United States Steel Corporation Applied Research Laboratory (Schapiro, Gray, and Eusner, 1961).

PETROGRAPHIC NOMENCLATURE

Some adherence to the nomenclature of Thiessen remains particularly in the United States. However, in the past 15 to 20 years, most of the world's petrologists have adopted the petrographic classification and nomenclature established by Stopes (1935) at the Heerlen Congress of Carboniferous Stratigraphy and Geology. This is now known as the Stopes-Heerlen System.

Recognizing the need for a better comprehension of all terms used in coal petrology nomenclature and for an international glossary of these terms, the Third International Conference on Carboniferous Stratigraphy and Geology appointed a committee in 1951 to review and relate the two principal systems of nomenclature, the Thiessen-Bureau of Mines and Stopes-Heerlen Systems. Efforts of the Committee for Coal Petrology Nomenclature resulted in the publication of two editions (1957; 1963) of a glossary. The international standard nomenclature of coal petrography, as published in the glossary of 1963, and the modified reflectance categories of Schapiro and Gray (1960) are employed in this report (table 1).

One of the recent accessions to the International Glossary is a classification, proposed by Spackman, who first presented in 1958 a framework in which new terms were introduced. This classification, presented in the 1963 edition of the Glossary as the "Coal Constituent Classification " (Spackman), was initially developed in the Coal Laboratories of The Pennsylvania State University. However, the terms now employed are based mainly upon the reflectance measurements of macerals established by Schapiro and Gray (1960) at the laboratories of the United States Steel Corporation in Monroeville, Pennsylvania. The terms are the principal ones employed in the petrographic laboratories that have developed in this country in the past five years.

Definition of Terms

An explanation of some of the common terms used in this report, based on work of Ammosov (1957), Schapiro and Gray and Eusner (1961), and Harrison (1961) may be helpful in applying petrographic data to carbonization evaluations.

Reactives

This term is applied to coal constituents that soften during carbonization and lose their physical and chemical characteristics. Examples of these reactives are vitrinite, exinite, and resinite (table 1).

Inerts

This term applies to those coal constituents that maintain their characteristics throughout the carbonization process or that are relatively little altered. Usually, they can be identified in the resulting coke with a microscope. Examples of inerts are inertinite, fusinite, and micrinite (table 1).

Stability Factor

This is a measure of coke strength and refers specifically to the percentage of a coke sample that is retained on a one-inch sieve after testing by the standard ASTM Tumbler Test procedure (American Society for Testing and Materials: Designation D 294-50). It is an indication of the resistance of coke pieces to breakage as they descend through the shaft of the blast furnace. Of the various physical evaluations for assessing quality of blast furnace coke, the stability factor is perhaps the most widely used in the United States. For this reason, coal petrography work related to coal carbonization is now correlated largely with this factor.

Optimum

In this paper, optimum refers to the best coking results that can be obtained with a standard set of operating conditions corresponding to good commercial operating practices. By varying these standard conditions, such as coal pulverization, coking rate, bulk density, etc., the optimum results also vary.

Reflectance Class

This term applies to grouping of reflectance values and is obtained by measuring the percentage of light reflected from the polished coal surfaces. Standard glasses with known reflectance percentage values were used to standardize the photometer. The percentage of light reflected from the vitrinite varied over a relatively large range depending upon the rank of coal from which the vitrinite was derived or the degree of coalification of the vitrinite particle. Arbitrary reflectance classes from 0 to 70 were assigned to cover the entire reflectance range (Schapiro and Gray, 1960). Readings of reflectance from 0.30 to 0.39 were expressed as vitrinite reflectance class 3, and readings of reflectance from 0.40 to 0.49 were expressed as vitrinite reflectance class 4, etc. The upper limit has been raised subsequently, from 70 to 80 as a result of studies of anthracite.

It appears, from experimental data, that exinite and resinite contribute to the quality of cokes to a degree comparable to, or perhaps even greater than, associated vitrinites. The percentage of reflectance from exinite and resinite is

TABLE 1 – MACERAL REFLECTANCE CLASSES AND
REACTIVITY DURING CARBONIZATION*

Reactives			Inerts		
Group Macerals	Macerals	Reflectance Class	Group Macerals	Macerals	Reflectance Class
Vitrinite		V0 to V21	Inert Vitrinite		V22 to V80
	Collinite	C0 to C21	Inert Resinite		R22 to R80
	Telinite	T0 to T21	Inertinite		I18 to I80
				Fusinite	F40 to F80
				Micrinite	M18 to M80
				Semifusinite†	SF22 to SF80
Exinite		E0 to E15		Sclerotinite	Sc22 to Sc80
	Sporinite	St0 to St15	Group Minerals	Minerals	
	Cutinite	Ct0 to Ct15			
	Alginite	At0 to At15	Sulphides	Pyrite, etc.	
	Resinite	R0 to R15	Carbonates	Calcite, etc.	
			Silicates	Illite, etc.	
Fusible Inertinite	Semifusinite† Micrinite	SF0 to SF21 M0 to M18			

* Nomenclature as defined in Glossary of International Committee for Coal Petrol-
ogy and based primarily on Stopes–Heerlen System of Classification. Range of re-
flectance values of macerals based on values of Schapiro, N. and Gray, R. J.,
1960, Petrographic Classification Applicable to Coals of All Ranks: Proceedings
of the Illinois Mining Institute, 68th year, p. 83–97.

† Estimated values, reactive group is about 1/3 and inert group about 2/3 of semi-
fusinite total, Ammosov, I. I., Eremin, I. V., Sukhenko, S. I., and Oshurkova,
L. S., 1957, Calculation of Coking Charges on the Basis of Petrographic Char-
acteristics of Coke: Koks i Khimiya, No. 12, p. 9–12.

generally lower than from associated vitrinite, especially in the high and medium volatile coals, therefore, in calculations, the total percentage of exinite and resinite has been prorated, or distributed proportionately, to vitrinite of reflectance classes 11 through 15 (Gray, personal communication 1961). In the present study, exinite and resinite have been distributed in the vitrinite classes according to this practice. However, in the 4 tests in which vitrinite 11 through 15 were absent, these components were allocated to the vitrinite 11 reflectance class.

Inert Index

An optimum coke can be produced from each vitrinite reflectance class (including other reactives allocated and equated to each class) provided that the proper ratio exists between the inerts and the vitrinite. The percentage of inerts required and the strength of the optimum coke will vary depending upon the degree of coalification (apparent rank) of the vitrinite, as measured by reflectance.

The relation between the percentage of inerts present in any given coal and the percentage of inerts needed in the coal to produce an optimum coke, is based on the apparent rank and the quantity of each inert present and is known as the inert index. The inert index can be calculated from Equation No. 1, which is given later in this paper.

Strength Index

The strength of the coke (calculated and expressed in arbitrary relative units) that is produced by blending various percentages of inerts with each vitrinite reflectance class is designated as the strength index for each particular mixture of reactives and inerts. The strength index of a coal or a blend that contains more than one vitrinite reflectance class, and generally most coals do, can be calculated by using Equation No. 2.

The arbitrary values for strength index, as developed by Schapiro and associates (1961), were based on about 400 micro-oven tests. These tests provide basic data for the strength index curves discussed below. These data were modified by data from 500 pound coke oven tests and the Russian tumbler data.

CURVES DEVELOPED FOR PREDICTING THE STABILITY FACTOR

Ammosov and associates (1957) developed a series of curves for predicting the coke stability factor. These curves were based on coal petrography data related to industrial coke tests using the Sundgren tumbler. A similar set of curves related to ASTM procedures has been developed by Schapiro and associates (1961). These investigators prepared a curve, similar to the one in figure 1, by plotting the different vitrinite reflectance classes as the abscissa and the ratio of reactives to inerts (R/I) as the ordinate, for the production of an optimum coke. The percentage of inerts necessary for production of an optimum coke for each vitrinite reflectance class is used as the M value in the calculation of the inert index (Equation No. 1). Equations 1 and 2, used in calculations necessary for predicting the stability factor, are discussed in later paragraphs.

A second set of data was plotted (Schapiro and associates, 1961) as a family of curves, similar to those shown in figure 2. Concentrates of vitrinite of each reflectance class that had varying percentages of inerts were coked in laboratory coke tests and arbitrarily tested for their relative coke strength. This provided
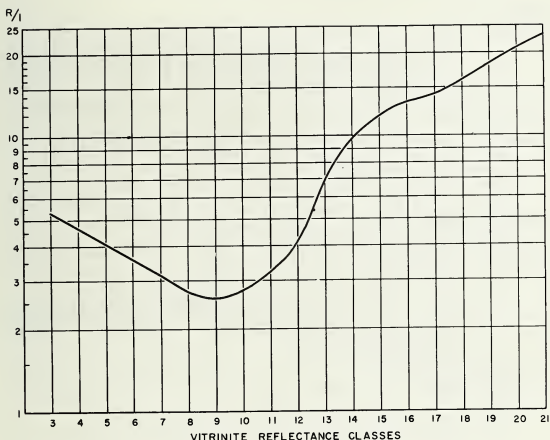
Figure 1 - Optimum ratio of reactives to inerts (R/I) for each vitrinite reflectance
class (modification of curve by Schapiro, Gray, and Eusner, 1961).

data for the "strength index," the ordinate in the figure. The percentage of inerts
was systematically varied for vitrinites of each reflectance class tested and was
plotted along the abcissa. Some of the original curves have been altered on the
basis of pilot scale coke test data in the present study. The figure (or the table
from which the figure is derived) provides the basis for determining the strength
index for each reflectance class in Equation 2.

A third essential procedure in the correlation of petrographic composition
and coke properties was provided by the various tests of Schapiro and associates
(1961) and involved the development of a graph similar to the one in figure 3. This
graph made use of a grid in which the strength index of a blend (composed of dif-
ferent reflectance classes and determined by the use of Equation 2) is plotted as
the ordinate and the inert index (determined by the use of Equation 1) is plotted
as the abscissa on a logarithmic scale. By testing coal blends which represented a
wide variety of possible combinations of strength and inert indices, it was possible
to construct a series of curves. These curves indicated the approximate positions
of the coke stability factors that vary between values of 10 to 65 (fig. 3).

The original curves that were compiled by Schapiro and associates (1961)
were used successfully for predicting the stability factor of coal blends containing
Illinois coals when the inert index (called "composition balance index" by Schapiro
and associates) was between 1.3 and 0.60. However, when the inert index dropped
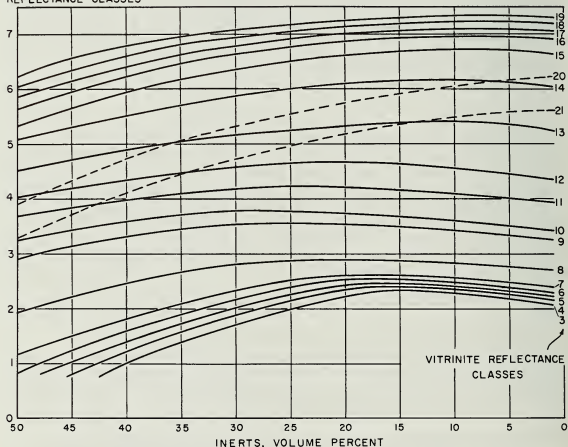
Figure 2 - Strength index for vitrinite reflectance classes depending upon the amount of inerts present (modification of curve by Schapiro, Gray, and Eusner, 1961).

below 0.6, the stability factors predicted from petrographic analysis were generally lower than the actual values obtained from pilot coke oven tests. A series of tests with Illinois coals in the Survey's pilot coke oven provided data that permitted changes in the curves of Schapiro and associates. These changes, which were incorporated into the curves shown in figure 3, make the curves applicable to most Illinois coal samples tested.

Procedures

Forty coke runs were made in the Survey's pilot coke oven, and coke test results were correlated with coal petrographic data. Various blends of Illinois high volatile bituminous coals and different percentages of medium and low volatile bituminous coals from the Appalachian fields were coked. In three series, Illinois and medium volatile coals were coked independently and then in blends consisting of 20 percent variations of the proportion of the two coals.
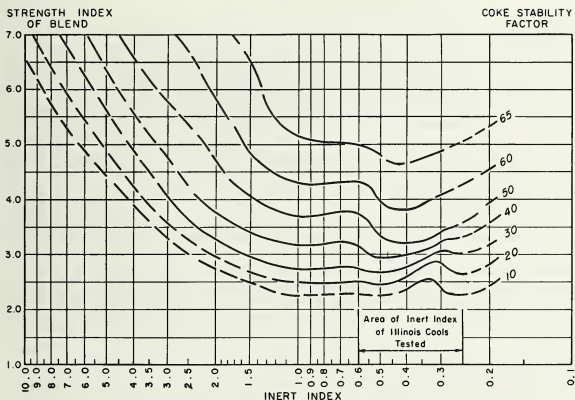
Figure 3 - Curves showing relation between strength index, inert index, and stability factor (modification of curves by Schapiro, Gray, and Eusner, 1961).

Coking Procedures

The pilot coke oven used for these tests has been operated for the past ten years for the Survey's metallurgical coke project (Jackman and associates 1955; also Illinois State Geological Survey Reprint Series, 1955 E). The coking chamber is approximately 36 inches deep, 36 inches high, and 17 inches wide (a commercial oven width), and it holds about 700 pounds of coal. Oven walls are heated electrically by nonmetallic heating elements. Flue temperatures may be regulated to duplicate any rate of heating normally used in commercial practice. With standard operating conditions, the cokes produced in the pilot oven duplicate closely the commercial cokes made from the same coal blends under equivalent heating conditions.

Petrographic Procedures

Representative samples of the coal or coal blend tested were taken for petrographic analysis, using sampling techniques similar to those used for obtaining samples for chemical analysis. To prevent excessive breakage of the more friable coal components, the coal sample was alternately crushed and screened until the entire sample passed through a 20-mesh Tyler sieve. Fifteen grams of this coal were added to a mixture of 5 grams of an epoxy resin (Biggs Bonding Agent 823) and 20 drops of hardener, placed in a cylindrical mold, and compressed for 10 to 15 minutes at 2000 pounds per square inch. Pressure was released, and the steel

cylinder was set aside until the coal briquette cured. After 10 to 13 hours at room temperature the briquette was ejected from the mold. It was ground on a Buehler Automet using 240 and 400 grit water-resistant emery paper, and was polished using Buehler alumina Nos. 1 and 3 in a water suspension on a nap free cloth. An essentially flat, scratch free surface was produced by this method of grinding and polishing. The sample was then ready for examination with the microscope.

Quantitative petrographic analysis, using the point count method (Chayes, 1956) for the percentage of reactive and of inert macerals and group macerals in each sample, was performed with the aid of a Leitz BMe microscope at a magnification of 320 X using an 8mm (25 X) oil immersion objective. The percentages of reactive macerals and inert macerals obtained by these analyses provided the basic data necessary to calculate the inert and strength indices, according to procedures outlined later.

The maximum percentage of incident light reflected from the polished surfaces of vitrinite fragments was measured, and the values were assigned to vitrinite reflectance classes. Vitrinite that has a reflectance value that exceeds 2.1 (reflectance class 22 and higher) has the apparent rank of anthracite and is classified as as an inert (table 1). Reflectance measuring equipment used in this investigation is similar to that described by Schapiro and Gray (1960). The Leitz UAM microscope, used for reflectance measurement of coal, is equipped with a photoelectric cell on the monocular tube which is, in turn, connected to a Photovolt photometer (Model 520 M). A pin hole diaphragm to restrict the area of measurable light on the sample to a 7 micron circle and a combination of two Eastman Wratten Filters, numbers 58 and 77, which provided a monochromatic light were placed in the monocular tube of the microscope through which all reflectance measurements were made. Reflectance values for most substances will vary if the wave length of light is altered; therefore, a restricted and constant wave length must be used to obtain accurate and reproducable reflectance readings. Six polished glass standards of known reflectance value were used to standardize the photometer at the beginning of the run and after each 25 reflectance readings. Reflectance values of these standards ranged from 0.306 to 1.832.

Calculations

Equations needed for calculating the two parameters, inert index and stability index, that are used for predicting coke stability factors from petrographic analysis are given below.

Inert Index

One of the values needed for predicting the stability factor of coke from petrographic analysis of coal is the inert index. This index expresses the relation between the inerts in a coal or blend and the reactives of each reflectance class. This is expressed in Equation 1.

$$N = \frac{Q}{\dfrac{P_1}{M_1} + \dfrac{P_2}{M_2} + \cdots + \dfrac{P_{21}}{M_{21}}}$$

when

N	= inert index
Q	= total percentage of inerts in the blend
P_1, $P_2 \ldots P_{21}$	= percentage of reactives in reflectance classes 1, 2, ...21 that may be present in the coal sample
M_1, $M_2 \ldots M_{21}$	= ratio of reactives to inerts (R/I) for the production of optimum coke for each reflectance class 1, 2,...21,

Values in Equation 1 are derived as follows:
Q, the total percentage of inerts in the blend (fusinite, micrinite, 2/3 semifusinite, and ash by volume), and P_1, P_2, etc., the percentage of reactives (vitrinite, exinite, resinite, and 1/3 semifusinite), can be taken from the petrographic analyses. Petrographic analyses for coals used in this study are shown in table 2. The values of M_1, M_2, etc., can be read from the curves in figure 1. For each vitrinite reflectance class represented in the reflectance analysis and shown on the abscissa of figure 1, project a vertical line to the curve. Then project a horizontal line to the ordinate at the left where the optimum ratio, or M value, can be read directly. These values can be placed in Equation 1 and the value of N, or inert index, calculated.

Strength Index

The strength index of the blend (K_T) is calculated by multiplying the strength index of each vitrinite reflectance class, by the percentage of reactives (vitrinite, exinite, resinite, and 1/3 semifusinite) in that reflectance class. The sum of these products is then divided by the total percentage of reactives in the blend. This is expressed in Equation 2.

$$K_T = \frac{(K_1 \times P_1) + (K_2 \times P_2) + \cdots + (K_{21} \times P_{21})}{P_T}$$

when

K_T	= strength index of the blend
P_T	= total percentage of reactives in the blend
K_1, K_2, ...K_{21}	= strength index of reactives in reflectances classes 1, 2, ...21 that may be present in the coal sample
P_1, P_2, ...P_{21}	= percentage of reactives in reflectance classes 1, 2, ...21 that may be present in the coal sample

Values in Equation 2 are derived as follows:
K_1, K_2, etc., are obtained from the family of curves in figure 2. Locate the point along the abscissa that corresponds to the percentage of inerts determined from the quantitative petrographic analysis of the coal sample. Project a vertical line from this point until it intersects the line for each vitrinite reflectance class present in the sample. Then project horizontal lines to the left until they intersect the ordinate. Read the strength index for each reflectance class from the numbers plotted along the ordinate. The values for P_1, P_2, etc., and P_T can be taken from petrographic analysis data such as in table 2. These data are put in Equation 2, and the strength index for the blend is calculated.

TABLE 2 – PETROGRAPHIC ANALYSES

Test No.	Reflectance class of reactive SF	Vitrinite reflectance classes in percent														
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
614E	10			5.0	37.4	13.8	0.4						2.5	10.0	8.6	1.4
617E	11		1.6	8.1	35.5	9.4	1.3	0.3	0.3	1.6	6.5	8.4	2.6	2.3	0.6	1.0
632E	11			1.8	12.0	17.8	10.0	1.5	0.4	0.7	2.9	7.1	4.3	5.3	7.4	1.5
634E	14			12.0	24.9	6.6	2.5	1.4		0.7	4.5	8.8	2.8	2.8	5.6	4.5
635E	11			10.4	25.4	8.6	3.0	0.4	0.4	0.8	3.2	8.2	3.6	3.2	7.0	3.6
649E	15						0.54	10.89	55.54	16.34	0.54					
650E	14			14.31	24.62	0.45		10.29	26.64	10.36	0.98	0.82				
653E	14			10.18	18.56			17.96	26.95	10.18						
654E	13			13.42	38.29	3.48		10.45	12.93	5.47						
660E	9			36.04	48.23	1.53										
662E	11			18.50	61.15	7.71										
663E	12				58.67	7.08					1.52	15.17	3.03			
664E	10				44.62	8.06					10.75	18.81	2.68			
665E	19			5.68	30.46	2.06					9.81	32.00	4.13			
666E	19				24.38	1.43					14.82	40.17	3.83			
667E	19										11.39	69.40	2.59			
668E	17									1.07	25.53	51.59	5.85			
669E	12			0.52	22.01	57.64	5.24									
670E	12			0.52	25.33	38.52	2.64				5.27	13.72				
671E	14				27.03	20.65	0.49			13.29	20.20		1.96			
672E	12				11.63	27.29	2.02				9.61	28.30	5.05			
673E	16				6.75	17.66	0.50				16.62	37.39	5.19			
675E	11		28.57	32.18							3.72	17.33	1.24			
676E	10		23.87	28.34	0.50						2.49	22.87	4.97			
677E	16		26.76	8.66							11.80	34.22	1.97			
678E	16			11.15	14.40						4.18	49.21	4.18			
679E	9	0.5	61.90	21.90												
695E	13			2.80	18.9	23.9	23.10	1.4								
696E	13			0.80	21.5	38.3	2.30	0.8			2.30	7.70	3.10			
697E	14			2.00	14.2	16.4	21.20	3.4					2.70	8.8	0.6	
698E	14				19.08	29.30	3.67				5.87	11.00	2.20	0.73	1.47	
704E	11			11.70	39.40	0.60				2.80	27.20	3.40				
705E	11			7.00	50.10	3.80				2.30	20.70	2.10				
720E	9			5.60	46.10	5.60	2.50	19.7	4.2							
722E	13			6.40	48.20	1.90	15.40	7.5	1.1							
723E	11			6.20	52.70	9.10	2.5	9.9	3.7							
733E	14			1.58	48.43	29.38										
734E	14			9.70	57.40	13.70										
772E	17		0.90	27.80	14.70	1.70				3.50	28.60	9.50				

TABLE 2 — Continued

19	Vitrinite	Exinite	Resinite	1/3 Semifusinite (reactive)	2/3 Semifusinite (inert)	Micrinite	Fusinite	Ash by Volume	Mean Reflectance V	Pr-total reactives	Q-total inerts	Inert Index	Strength Index	Measured stability	Predicted stability Original curves	Predicted stability Revised curve
0.4	79.50	3.60	0.50	0.20	0.50	8.70	3.00	3.80	1.03	83.80	16.20	0.79	3.97	55.8	54	54
0.3	79.80	3.20	0.40	0.10	0.10	10.20	2.80	3.40	0.96	83.50	16.50	0.79	3.75	61.2	50	51
0.4	73.10	6.20	0.40	0.30	0.70	11.90	3.90	3.50	0.84	80.00	20.00	1.03	4.54	58.4	61	61
	77.10	3.80	0.60	0.20	0.50	10.90	2.50	4.40	1.07	81.70	18.30	1.01	4.24	55.4	58	57
0.8	79.20	4.10	0.20	0.20	0.50	9.90	2.70	3.20	1.08	83.70	16.30	0.86	4.28	60.2	58	60
	83.85	0.88	0.79	0.46	0.92	8.45	1.87	2.78	1.16	85.98	14.02	0.54	4.17	58.3	47	56
	84.10	3.33	0.29	0.75	1.50	4.99	1.96	3.08	0.95	88.47	11.53	0.44	3.44	51.8	39	52
	83.83	2.66	0.29	0.26	0.53	7.97	1.48	2.98	0.98	87.04	12.96	0.48	3.56	53.5	43	54
	84.04	3.32	0.09	0.23	0.45	8.20	0.59	3.08	0.69	87.69	12.32	0.46	3.12	48.9	34	47
	85.80	5.85	0.19	0.49	0.97	2.82	0.58	3.30	0.70	92.33	7.67	0.28	2.60	16.5	8	18
	87.36	4.49	0.39	0.13	0.26	3.22	0.59	3.56	0.73	92.37	7.63	0.27	2.61	21.9	6	21
	85.47	3.70	0.68	0.26	0.52	4.57	1.56	3.24	0.93	90.11	9.89	0.43	3.55	56.1	41	56
	84.92	3.14	0.29	0.29	0.59	6.27	1.66	2.84	1.01	88.64	11.36	0.54	3.96	61.6	50	58
	84.14	2.46	0.39	0.26	0.53	7.58	2.17	2.47	1.11	87.25	12.75	0.77	4.54	63.1	63	63
	84.63	1.28	0.29	0.46	0.91	8.64	1.57	2.22	1.22	86.66	13.34	0.93	5.00	65.2	64	64
	83.38	0.00	0.10	0.53	1.05	9.51	3.56	1.87	1.43	84.00	16.00	1.99	6.00	60.9	57	61
	84.04	0.00	0.00	0.82	1.65	9.20	2.77	1.52	1.42	84.86	15.40	1.66	5.95	62.8	62	62
	85.40	5.30	1.20	0.17	0.33	2.80	1.20	3.60	0.82	92.10	7.90	0.24	2.87	23.5	11	23
	86.00	3.34	0.79	0.29	0.59	4.13	1.77	3.09	0.95	90.42	9.58	0.37	3.58	53.7	39	54
	83.59	2.84	0.88	0.29	0.59	6.57	2.74	2.50	1.06	87.60	12.40	0.60	4.15	59.6	55	58
	83.90	2.16	0.39	0.42	0.85	7.95	1.86	2.47	1.14	86.87	13.13	0.68	4.51	63.0	61	63
	84.11	1.48	0.29	0.23	0.46	8.76	2.66	2.01	1.09	86.11	13.89	0.92	5.06	64.4	64	64
	82.94	4.12	1.27	0.23	0.46	5.10	2.75	3.14	0.82	88.56	11.44	0.63	3.59	43.9	46	46
	83.04	3.44	1.28	0.46	0.92	5.70	2.46	2.70	0.92	88.22	11.78	0.70	4.00	55.5	53	55
	83.41	2.47	1.09	0.56	1.12	6.51	2.47	2.37	1.06	87.53	12.47	0.88	4.58	59.8	63	61
	83.12	1.29	0.49	0.49	0.99	8.00	3.56	2.07	1.19	85.39	14.61	1.22	5.05	63.8	66	65
	84.33	5.59	2.06	0.26	0.53	2.75	1.18	3.30	0.57	92.24	7.76	0.33	2.72	13.5	15	13
	70.10	12.00	1.30	1.00	2.00	7.90	3.10	2.60	0.82	84.40	15.60	0.52	3.20	24.3	37	43
	76.80	8.00	1.40	0.70	1.50	6.10	2.70	2.80	0.92	86.90	13.10	0.53	3.67	41.1	47	51
	69.30	9.00	2.20	1.20	2.30	1.03	3.10	2.60	1.00	81.70	18.30	0.70	3.79	49.9	57	50
	73.40	9.80	1.80	0.60	1.30	7.30	3.20	2.60	1.01	85.60	14.40	0.64	3.98	47.2	53	53
	85.10	3.40	0.20	0.20	0.50	6.40	0.80	3.40	0.98	88.90	11.10	0.52	3.75	58.3	47	55
	86.00	3.00	1.00	0.60	1.30	2.30	2.00	3.80	0.92	90.60	9.40	0.31	3.47	53.8	35	53
	83.70	3.80	0.70	0.90	1.70	5.00	1.10	3.10	0.85	89.10	10.90	0.37	2.98	36.1	28	36
	80.50	4.60	0.80	0.60	1.10	7.80	1.70	2.90	0.82	86.50	13.50	0.46	2.97	38.6	30	40
	84.10	4.10	0.10	0.30	0.70	6.00	1.50	3.20	0.81	88.60	11.40	0.40	2.86	33.0	23	31
	79.40	6.30	0.30	0.50	0.90	3.00	5.20	4.20	0.78	86.40	13.60	0.50	2.97	39.7	31	40
	80.80	5.50	0.60	0.40	0.90	1.90	5.70	4.20	0.75	87.30	12.70	0.49	2.89	41.2	28	39
	86.70	2.80	0.10	0.60	1.40	1.70	3.10	3.60	1.01	90.20	9.80	0.51	4.10	66.3	52	61

Based on additional information gained through tests described in this report, the family of curves shown in figure 2 has been altered from the curves, presented by Schapiro and associates (1961). Curves for vitrinite reflectance classes 3 to 8 have been moved closer to the curves 9 to 21. This adjustment allowed greater accuracy in predicting stability factors that more nearly agree with results obtained in the present series of tests.

The next step in predicting the stability factor is to establish the location of a point on figure 3, based on inert and strength indices values, and to evaluate the position of this point within the pattern of stability factor curves present. The point is established by projecting a vertical line from the inert index value, which is plotted on the abscissa, to the point where it intersects a horizontal line projected from the strength index value, which is plotted on the ordinate. The predicted stability factor is determined by the relation of this point to the stability factor curves.

Results

Petrographic Data

Normally, most vitrinite, in the different ranks of coal, falls into two or three reflectance classes although minor percentages may be determined in the next higher and/or lower classes. Generally one vitrinite reflectance class is found to be dominant in each rank of coal. However, if most vitrinite reflectance measurements of an individual coal are near the boundary of an arbitrarily established reflectance class, such as 0.79 (reflectance class 7) or 0.8 (reflectance class 8), most of the vitrinite will be distributed in two reflectance classes (table 2).

Dominant reflectance measurements associated with two widely spaced reflectance classes indicate that two coals of appreciable rank difference are present in the blend (table 2). If, on the other hand, coals of a similar rank are blended, distinction between these coals by reflectance data may be difficult.

Vitrinite in high volatile C bituminous coal from Illinois normally ranges from reflectance class 4 through 7, but the predominant reflectance class is 6. The vitrinite reflectance class predominant in Herrin (No. 6) Coal of high volatile B rank is 7, and it ranges from 6 through 8. Harrisburg (No. 5) Coal samples from Illinois used in this study are of high volatile B rank, but their slightly higher position in high volatile rank is indicated by a predominance of vitrinite reflectance class 8 and it ranges from 6 through 9.

In this study, vitrinites in the medium volatile coals had a somewhat higher reflectance than vitrinites in the high volatile coals. There was a predominance of reflectance class 14 in the medium volatile coals.

The one low volatile coal included in this investigation was not coked by itself because of fear of the high expansion pressures that might have been exerted on walls of the coke oven. The predominant vitrinite reflectance classes of this coal found in the blends were 16 and 17.

Quantitative petrographic analyses of the coals and blends used in the tests of this study are given in table 2. Vitrinite is the predominant group maceral and makes up 70 to 87 (average 83) percent of the total composition. Exinite varies from about 1 to 12 percent of the total composition, but most blends contained less than 6 percent of this component. Resinite is present in small quantities, usually

less than one percent, but some blends contain up to 2.2 percent. Semifusinite, which is regraded as gradational between vitrinite and fusinite, is classified arbitrarily as 1/3 reactives and 2/3 inerts, following the practice of Ammosov and associates (1957) and Schapiro and associates (1961). A number of reflectance measurements of semifusinite are made and an average obtained. One third of the semifusinite, recorded in the maceral analysis, is allocated to the vitrinite reflectance class that has the same value as the average semifusinite value. Semifusinite is generally present in small quantities, less than 1.5 percent, in this study but it is reported as high as 3.5 percent. Micrinite, the predominant inert in this series of tests, averages 6.5 percent and ranges from 1.7 to 10.3 percent.

Chemical Analysis

Routine proximate analyses are reported for each coal, each blend of coal, and the resulting coke. These analyses are given in table 3. Direct correlation of chemical data with petrographic data is difficult because a proximate analysis treats the coal as a single substance, not as a substance composed of various coal components with different physical and chemical composition. However, a general relation between the mean reflectance of vitrinite (table 2) and the dry, ash free value for fixed carbon (table 3) can be shown in these tests. As the mean reflectance of the vitrinite increases the percentage of fixed carbon increases.

Ultimate chemical analysis of the individual vitrinites is more amenable to correlation with petrographic variability, than is proximate analyses of this type; however, ultimate chemical analyses were not available for this study.

Coking Results

The coking results reported in table 3 were obtained under standardized operating conditions in the Survey pilot coke oven. In addition to the three series of tests using blends of Illinois coal and medium volatile coal mentioned previously in this paper, coking and petrographic analyses of other blends that were being studied for the Survey's general coke evaluation project were included in this study.

Although the present petrographic studies have been concerned with correlations based on actual and calculated tumbler stability factors, the complete carbonization results, including tumbler tests, shatter tests, coke sizing, apparent gravity and expansion pressure values, are submitted in table 3. In addition, data on coal pulverization and coking time and also proximate analyses of all coal blends and cokes, are included. These data may be of value in future studies that correlate petrographic data with other coke properties.

Relation Between Measured and
Predicted Coke Stability Factors of This Study

Illinois coals and blends that contain a high percentage of Illinois coals generally have an inert index that lies between 0.6 and 0.25 on the abscissa of figure 3. If data obtained in this investigation are plotted on the curves as reported by Schapiro and associates (1961), the stability factor is found to be lower than the measured ASTM tumbler stability in pilot oven cokes produced. Relatively small modifications of the curves were made in order to obtain close correlation between the predicted and measured stability factors.

TABLE 3 — PILOT PLANT COKING RESULTS AND CHEMICAL ANALYSES

Blends in percent	Test No.	Tumbler Test		Shatter Test			Sizing					
		Stability	Hardness	+2"	+1½"	+1"	+4"	4"x3"	3"x2"	2"x1"	1"x½"	-½"
55 Ill. No. 6 (½" x 0); 20 Ill. No. 5; 25 Pocahontas	614E	55.8	65.2	72.5	90.6	96.2	5.3	23.8	38.4	23.0	1.6	7.9
70 Ill. No. 6 (½" x 0); 30 Jewell	617E	61.2	72.0	69.8	90.6	96.7	4.8	15.4	44.9	28.3	1.5	5.1
45 High Splint; 15 Cedar Grove; 40 Pocahontas	632E	58.4	70.2	67.6	88.8	96.3	2.1	10.8	47.9	33.9	1.7	3.6
45 Ill. No. 6 (3" x 0); 15 Cedar Grove; 40 Pocahontas	634E	55.4	68.8	71.5	89.7	96.3	3.4	21.9	41.9	26.5	2.1	4.2
45 Ill. No. 6 (3" x 10m); 15 Cedar Grove; 40 Pocahontas	635E	60.2	69.9	69.6	90.9	96.5	1.4	16.7	45.5	31.1	1.6	3.7
100 Tiller	649E	58.3	67.1	77.6	91.3	96.7	5.0	15.5	50.8	23.3	1.8	3.6
40 Ill. No. 6 (2" x 1"); 60 Tiller	650E	51.8	61.7	67.6	89.0	96.0	3.1	10.7	48.7	32.4	1.6	3.7
25 Ill. No. 6 (2" x 1"); 75 Tiller	653E	53.5	64.5	72.3	90.2	96.6	2.7	14.8	49.9	27.0	1.7	3.9
55 Ill. No. 6 (1½" x 1"); 45 Tiller	654E	48.9	61.6	69.0	89.4	95.8	1.9	14.8	48.1	29.0	2.1	4.1
100 Ill. No. 6 (2" x 1")	660E	16.5	66.2	33.8	63.0	83.0	0.0	5.2	20.7	65.1	5.0	4.0
100 Ill. No. 6 (3" x 0)	662E	21.9	65.4	44.0	69.0	86.4	0.0	5.4	20.8	63.2	6.1	4.5
80 Ill. No. 6 (3" x 0); 20 Jewell	663E	56.1	67.2	67.9	90.0	96.1	1.1	16.5	46.7	29.5	1.9	4.3
60 Ill. No. 6 (3" x 0); 40 Jewell	664E	61.6	69.9	72.2	92.1	96.7	1.7	13.4	50.6	29.0	1.5	3.8
40 Ill. No. 6 (3" x 0); 60 Jewell	665E	63.1	70.1	76.0	93.2	97.6	2.6	19.1	44.9	28.8	1.2	3.4
20 Ill. No. 6 (3" x 0); 80 Jewell	666E	65.2	71.0	80.3	93.5	97.6	0.0	19.6	48.7	27.5	1.0	3.2
100 Jewell	667E	60.9	65.5	84.5	94.8	97.6	5.0	22.5	46.4	20.8	1.5	3.8
100 Sewell	668E	62.8	66.8	85.0	95.5	97.9	5.8	22.6	51.2	15.9	1.2	3.3
100 Ill. No. 5 (3" x 0)	669E	23.5	66.5	50.4	75.2	87.4	0.0	6.7	27.1	56.7	5.2	4.3
80 Ill. No. 5 (3" x 0); 20 Sewell	670E	53.7	66.1	67.7	89.2	95.8	3.6	15.6	47.5	27.1	2.0	4.2
60 Ill. No. 5 (3" x 0); 40 Sewell	671E	59.6	67.9	72.4	92.9	97.1	2.8	17.6	46.5	27.9	1.3	3.9
40 Ill. No. 5 (3" x 0); 60 Sewell	672E	63.0	69.3	77.1	93.5	97.6	1.4	15.4	51.7	26.6	1.4	3.5
20 Ill. No. 5 (3" x 0); 80 Sewell	673E	64.4	69.3	84.1	95.2	97.9	5.8	21.8	49.2	18.4	1.2	3.6
80 Ill. No. 7 (1½" x ¼"); 20 Jewell	675E	43.9	57.3	72.7	88.9	94.7	3.3	19.5	44.9	25.2	2.9	4.2
60 Ill. No. 7 (1½" x ¼"); 40 Jewell	676E	55.5	64.5	73.6	90.7	96.2	3.1	17.4	47.7	25.8	1.6	4.4
40 Ill. No. 7 (1½" x ¼"); 60 Jewell	677E	59.8	67.8	76.9	91.9	97.0	2.1	16.3	48.1	28.5	1.3	3.7
20 Ill. No. 7 (1½" x ¼"); 80 Jewell	678E	63.8	70.5	75.3	92.9	97.5	2.0	19.1	50.5	24.2	1.1	3.1
100 Ill. No. 7 (1½" x ¼")	679E	13.5	62.0	46.8	69.8	83.6	1.1	12.9	33.3	38.5	8.3	5.9
15 Ill. No. 6 (3" x 0); 70 Harlan, Ky.; 15 Pocahontas	697E	49.9	65.2				5.2	22.1	45.1	20.5	3.1	4.0
5 Ill. No. 6 (3" x 0); 80 Harlan, Ky.; 15 Pocahontas	698E	47.2	64.4				3.5	19.1	45.5	25.2	2.4	4.3
60 Ill. No. 6 (3" x 0); 40 Pocahontas (Med. Vol.)	704E	58.3	66.5	79.2	91.8	96.8	3.6	16.5	48.3	25.7	1.5	4.4
70 Ill. No. 6 (3" x 0); 30 Pocahontas (Med.-Vol.)	705E	53.8	64.8	78.2	92.4	96.6	2.8	22.1	46.1	23.5	1.6	3.9
65 Ill. No. 6 (½" x 28m); 35 Splashdam	720E	36.1	55.7				6.4	26.9	39.3	20.5	2.7	4.2
50 Ill. No. 6 (½" x 28m); 50 Splashdam	722E	38.6	55.1				7.1	23.1	44.4	19.1	2.4	3.9
80 Ill. No. 6 (½" x 28m); 20 Splashdam	723E	33.0	56.0				4.6	21.8	44.0	22.0	3.2	4.4
100 Ill. No. 6 (½" x 0)	733E	39.7	58.4				3.2	21.9	45.3	18.8	3.2	7.6
100 Ill. No. 6 (3" x 0); Fine Pulverization	734E	41.2	53.1				3.4	20.7	38.6	20.8	2.2	14.3
50 Ill. No. 6 (3" x 1"); 50 Basin	772E	66.3	73.0	72.0	91.9	97.3	2.8	18.2	51.3	23.6	1.1	3.0
20 Ill. No. 6 (3" x 0); 80 E. Ky. "B"	695E	24.3	62.2				1.7	16.8	36.7	33.7	5.6	5.5
10 Ill. No. 6 (3" x 0); 80 E. Ky. "B"; 10 Pocahontas 3	696E	41.1	61.3				2.8	20.1	45.8	24.1	3.1	4.1

TABLE 3 — CONTINUED

Average Size (")	Apparent Gravity	Expansion Pressure lbs./sq."	@ bulk density of lbs./cu.ft.	Coal Pulverization Minus 1/8"	Minus 100 mesh	Coking Time (17" oven) Hr.:Min.	Analyses Coal M	VM*	FC*	Ash*	Sulfur*	Coke VM*	FC*	Ash*	Sulfur*
2.41	0.830	0.95	52.2	85.6	20.4	16:30	6.7	31.8	60.7	7.5	1.04	1.3	87.8	10.9	0.87
2.32	0.835	1.65	53.6	87.4	20.9	16:30	6.5	31.9	61.3	6.8	0.93	1.4	88.9	9.7	0.80
2.20	0.865	0.95	51.0	79.9	16.5	16:30	3.4	30.8	64.9	4.3	0.58	0.9	92.9	6.2	0.54
2.39	0.865	0.85	51.7	81.8	17.2	16:30	5.6	29.3	64.4	6.3	0.79	1.1	90.4	8.5	0.76
2.27	0.840	1.00	51.2	81.2	21.3	16:30	6.0	30.6	63.8	5.6	0.85	1.0	91.3	7.7	0.76
2.41	0.875	0.95	50.0	81.1	10.8	16:30	2.8	29.1	65.0	5.9	0.59	1.0	91.4	7.6	0.54
2.24	0.855	0.85	50.0	83.2	12.9	16:30	5.8	32.3	61.5	6.2	0.80	1.8	89.7	8.5	0.67
2.31	0.830	0.80	49.8	81.5	8.7	16:30	5.2	31.1	62.9	6.0	0.76	1.0	90.9	8.1	0.65
2.27	0.820	–	50.0	76.6	7.4	16:30	6.8	34.2	60.0	5.8	0.89	0.8	90.8	8.4	0.70
1.72	0.740	0.55	50.0	75.0	5.9	16:30	8.2	38.9	54.5	6.6	1.14	1.0	89.1	9.9	0.86
1.71	0.735	0.65	50.8	76.1	7.3	16:30	8.1	38.7	54.2	7.1	1.16	1.3	88.6	10.1	1.00
2.26	0.750	0.80	50.2	76.6	9.3	16:30	7.8	35.3	58.2	6.5	1.11	1.0	89.8	9.2	0.89
2.27	0.805	0.85	50.4	78.8	9.7	16:30	6.0	32.2	62.1	5.7	1.01	0.9	91.5	7.6	0.82
2.34	0.820	0.95	50.7	81.0	11.6	16:30	5.6	27.8	67.2	5.0	0.84	0.7	91.7	6.7	0.66
2.33	0.885	1.25	50.9	82.8	12.8	16:30	4.1	25.0	70.5	4.5	0.67	0.6	93.8	5.6	0.55
2.51	0.855	1.50	50.1	84.7	12.0	16:30	3.5	21.7	74.5	3.8	0.61	0.7	94.6	4.7	0.49
2.59	0.830	2.05	50.1	84.0	11.5	16:30	4.0	23.5	73.4	3.1	0.67	0.7	95.4	3.9	0.45
1.81	0.765	0.60	50.2	73.2	6.2	16:30	6.3	37.1	55.8	7.1	1.40	1.0	89.0	10.0	1.15
2.33	0.795	0.70	50.3	77.0	7.5	16:30	5.7	34.1	59.7	6.2	1.31	0.7	90.7	8.6	0.99
2.34	0.810	0.90	50.2	79.4	8.6	16:30	5.0	30.5	64.4	5.1	1.05	0.8	92.0	7.2	0.81
2.31	0.860	0.95	50.2	80.1	7.8	16:30	4.6	29.3	65.7	5.0	0.96	0.7	92.7	6.6	0.73
2.55	0.845	1.90	50.5	81.6	9.9	16:30	4.1	26.9	69.0	4.1	0.81	0.5	94.3	5.2	0.62
2.36	0.790	0.45	50.0	78.4	8.5	16:30	9.3	39.9	53.8	6.3	1.91	1.0	89.9	9.1	1.42
2.35	0.815	0.65	51.2	77.8	9.6	16:30	7.8	33.9	60.6	5.5	1.55	0.8	91.6	7.6	1.12
2.31	0.855	0.75	50.3	80.9	11.5	16:30	5.8	29.1	66.1	4.8	1.15	0.6	92.8	6.6	0.95
2.40	0.900	1.10	51.8	80.4	12.2	16:30	4.1	26.0	69.8	4.2	0.90	0.5	94.0	5.5	0.70
1.99	0.785	0.50	50.3	82.6	7.4	16:30	10.9	44.9	48.5	6.6	2.11	0.9	88.8	10.3	1.63
2.48	0.845	0.80	51.0	77.6	8.2	16:30	3.5	35.2	59.5	5.3	0.79	0.8	91.5	7.7	0.61
2.37	0.855	0.90	51.3	77.5	8.3	16:30	2.6	34.9	59.8	5.3	0.73	0.7	91.7	7.6	0.58
2.35	0.785	0.90	50.5	82.7	9.1	16:30	6.4	29.7	63.5	6.8	0.84	0.9	89.6	9.5	0.68
2.43	0.780	0.65	50.2	81.1	8.9	16:30	7.4	32.7	59.8	7.5	0.86	0.9	88.5	10.6	0.68
2.55	0.815	0.55	50.5	57.1	3.2	16:30	5.7	34.3	59.5	6.2	1.19	0.9	90.3	8.8	0.95
2.55	0.820	0.71	48.6	64.8	1.7	16:30	7.3	35.3	58.3	6.4	1.34	0.8	89.9	9.3	1.10
2.43	0.760	0.55	49.1	50.2	2.8	16:30	7.3	35.3	58.3	6.4	1.34	0.8	89.9	9.3	1.10
2.37	0.745	0.80	50.2	75.9	8.9	16:30	10.6	36.6	55.5	8.5	1.04	1.6	85.6	12.9	0.92
2.21	0.735	0.65	49.7	93.8	12.7	16:30	10.0	37.2	54.2	8.6	1.09	1.9	85.3	12.8	1.01
2.42	0.845	1.10	51.7	88.5	11.2	16:30	4.9	30.2	62.6	7.2	0.85	1.1	90.6	9.6	0.75
2.14	0.840	0.85	49.7	79.1	7.1	16:30	3.7	37.5	57.0	5.5	0.79	0.7	91.2	8.1	0.64
2.37	0.845	0.70	50.2	78.1	7.8	16:30	3.1	36.2	58.2	5.6	0.76	0.8	91.7	7.5	0.65

* Moisture Free

A comparison of the measured stability factors that were derived from the standard ASTM tumbler test of coke produced in the Survey's pilot coke oven, and the predicted stability factors, is given in table 2. One set of predicted stabilities was derived from the curves of Schapiro and associates (1961); the other set of predictions was based on the revised curves constructed as a result of this investigation. For example, in the series of runs from 649E to 664E, where the inert index was less than 0.6, predictions based on the original curves of Schapiro (1961) are appreciably lower than the measured stability. Prediction of stability factors based on the revised curves (fig. 3) were in most cases nearly the same as the ASTM stability factors determined on the cokes from pilot oven tests.

Special attention is called to test number 670E (table 2) that illustrates the calculations used for predicting the coke stability factor from petrographic analysis of coal. Table 4 is a work sheet on which data are compiled from petrographic analyses (table 2), and from curves in figures 1, 2, and 3.

Data on lines 1 through 5 in table 4 are taken from the petrographic analyses in table 2. Line 1 gives the percentage of each vitrinite reflectance class, as determined from petrographic analysis. In this case, the sum of all vitrinite equals 86 percent.

Line 2 gives the values for one-third of the semifusinite that has been allocated to the appropriate reactive vitrinite reflectance class. The value of the semifusinite is based on the average of reflectance values of semifusinite determined in the reflectance analysis. In this case it was allocated to vitrinite reflectance class 12. Line 3 allocates prorated values of the reactives, exinite and resinite, to vitrinite reflectance classes 13 and 14, based on the percentage of these reactives in the sample. The sum of the items on line 3 equals 4.13.

Line 4 gives the percentage of total reactives in, and allocated to the different vitrinite reflectance classes. These values are represented by P in Equations 1 and 2. The sum of the items on line 4 equals 90.42. This is the total percentage of reactives in the blend, or P_T of Equation 2. Line 5 is the total percentage of inerts in the blend (9.58), or Q of Equation 1.

Values for lines 6 and 7 are taken from the curves in figures 1 and 2, respectively. The values for the optimum ratio of reactives to inerts for production of optimum coke for each vitrinite reflectance class represented is recorded on line 6 of table 4. These are the values for M in Equation 1. The strength index for each vitrinite reflectance class present is recorded on line 7 and is represented by K in Equation 2.

Substituting these values in Equations 1 and 2 gives the following:

Equation 1

$$N = \cfrac{Q}{\dfrac{P_1}{M_1} + \dfrac{P_2}{M_2} + \cdots + \dfrac{P_{21}}{M_{21}}}$$

$$N = \cfrac{9.58}{\dfrac{.52}{3.6} + \dfrac{25.33}{3.2} + \dfrac{38.52}{2.7} + \dfrac{2.64}{2.5} + \dfrac{0.29}{4.0} + \dfrac{6.42}{6.8} + \dfrac{16.70}{11.4}}$$

$$N = \frac{9.58}{0.14 + 7.92 + 14.27 + 1.06 + 0.07 + 0.95 + 1.47}$$

$$N = \frac{9.58}{25.88} = 0.37 \quad \text{(inert index)}$$

Equation 2

$$K_T = \frac{K_1 \times P_1 + K_2 \times P_2 + \cdots + K_{21} \times P_{21}}{P_T}$$

$$K_T = \frac{(2.5)(.52) + (2.6)(25.33) + (2.8)(38.52) + (3.4)(2.64) + (4.5)(0.29) + (5.4)(6.42) + (6.2)(16.70)}{90.42}$$

$$K_T = \frac{323.50}{90.42} = 3.58 \quad \text{(strength index)}$$

By plotting the inert index of 0.37 and strength index of 3.58, obtained from the calculations above, on figure 3 we can predict a stability factor of 54 for the coke produced from this coal. The predicted stability factor from the original published curves of Schapiro and associates is 39. The stability of coke produced in the Illinois Survey's pilot coke oven was 53.7

Coking conditions such as rate of heating, charging temperature, and final coking temperature were standardized, as were coal preparation procedures. ASTM standard procedures were used in testing the coke.

The measured stability and predicted stability were not in agreement with values predicted from the curves compiled by Schapiro and associates or with the revised curves for tests 695E, 696E, and 617E (table 2). This indicates that conditions of coking, or some characteristic of the coal not considered in investigations from which these curves were compiled, exerted an influence on the coke produced in these three tests. Additional studies are necessary to evaluate the possible causes of such inconsistencies.

TABLE 4 - WORK SHEET FOR PETROGRAPHIC DATA FOR PREDICTONG THE STABILITY FACTOR OF COKE
(Test No. 670 in Table 2)

Line	Description	Vitrinite reflectance classes							
		6	7	8	9	12	13	14	Total
1.	Percentage of Vitrinite in each reflectance class	.52	25.33	38.52	2.64		5.27	13.72	= 86.00
2.	1/3 Semifusinite - (Average reflectance equated to V.)					0.29			
3.	Prorated values of exinite and resinite from V 11 to V 15						1.15	2.98	= 4.13
4.	P - Percentage of total reactives in each reflectance class	.52	25.33	38.52	2.64	0.29	6.42	16.70	= 90.42 = P_T
5.	Q - Percentage of total inerts - (Including 2/3 SF)								9.58 = Q
6.	M - Optimum ratio of reactives to inerts for each reflectance class	3.6	3.2	2.7	2.5	4.0	6.8	11.4	
7.	K - Strength index for each reflectance class	2.5	2.6	2.8	3.4	4.5	5.4	6.2	

SUMMARY

Recently assembled petrographic data on Illinois coals and certain blends of Illinois coals and higher rank Eastern coals have been presented. This information has been used to demonstrate the possibility of effective use of petrographic analysis in the assessment of the ASTM tumbler stability factors of cokes. Although petrographic data can be used for predicting the effect of carbonization without a detailed understanding of the science involved, the method of acquiring and handling the data in the laboratory, as well as the calculations and graphs have been described in some detail for those who may desire a better understanding of this scientific tool.

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